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THE SPECTRA OF THE HEAVY ELEMENTS

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THE SPECTRA OF THE HEAVY ELEMENTS

By Frank S. Tomkins and Mark Fred

This paper lists the most prominent spectrum lines of the elements from protactinium to americium. In most cases, the spectra were made available because of the necessity of conducting spectrochemical analyses on a number of samples for impurities.* Because of limitations of sample size, it was not feasible to perform the analyses with the aid of chemical or physical[1] separations, and so the spectrum of the major constituent was always present. It would be of considerable interest to provide descriptions of the spectra which would be adequate for term analyses leading to energy levels and electron configurations, not only for the spectroscopic interest but also for the assistance they might provide in the correlation of chemical properties of these elements. However, the amounts of labor and sample required for such descriptions are quite formidable, as is evidenced by the fact that the spectra of thorium and uranium are still incompletely analyzed in spite of their having been available in unlimited quantities for many years. To be adequate for a term analysis, the wavelengths must be measured to the third decimal place for as many lines as can be observed over the most extensive wavelength range accessible; Zeeman patterns must be provided; and a temperature or excitation varation must be provided in order to distinguish the various stages of ionization and low levels from high levels. On the other hand, for purposes of identification, it is sufficient to have measurements of the strongest lines of each element, accurate to the first decimal place, covering a representative wavelength region that is convenient for analysis. Since it will probably be some time before data of much value for term analyses are accumulated, the following information was collected for whatever usefulness it might have in spectrochemical analyses. However, it was found on closer examination of the assembled data that statistical considerations indicated that the analogy between the heavy elements and the rare earths was closer than had been anticipated, and in fact was sufficient to permit some conclusions to be made regarding electron configurations.

The spectra were taken on a Baird 3-meter spectrograph, which covers a range of 1400 A in the first order. For comparison with the standard plates of the elements which had been prepared for analytical purposes, the samples were exposed in the region 2650-4050 A, corresponding to an angle of incidence of 3.3°. A second exposure was usually made at an angle of

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*The spectrum of plutonium was first photographed by Rollefson and Dodgen, of the University of California at Berkeley, who reported[2] wavelengths and arbitrary intensities for about 125 lines, later extended[3] to about 700 lines.

incidence of 11.5°, covering the region 3700-4370 A in the second order, since this region is quite useful for the detection of many elements with complex spectra, such as the rare earths. The intensity distribution of the particular grating employed in the spectrograph is such that equal background intensities are obtained for the same exposures at the two angles of incidence, and consequently the intensities observed in the second order were divided by 2 to reduce all intensities to the first order scale. The wavelengths were measured by comparison with neighboring iron lines, using a 0.1-mm scale taken from a Bausch and Lomb measuring eyepiece, in an Applied Research Laboratory comparator-densitometer, which provided dual projection of spectra and scale on a ground glass screen, with a twenty-fold magnification. The wavelengths should be accurate to better than 0.1 A.

The spectra were obtained by the copper spark method[4] developed in this laboratory for such applications. This method has the advantage, in addition to high absolute sensitivity, of providing fairly reproducible intensities. Hence a measure of the intensity of each line could be obtained conveniently by exposing successively diluted samples and determining the limiting amount of the element at which the line could be distinguished above the continuous background of the source. The limits were obtained by visual inspection and should be accurate to a factor of 2. The intensities were then expressed as one hundred times the reciprocal of the limiting weight in micrograms on the electrode, the factor being chosen to avoid fractional intensities. An essential advantage of this method of indicating intensities is the fact that all elements are described by the same intensity scale.

The spectra of protactinium, neptunium, plutonium, and americium are given in Tables 1, 2, 3, and 4, respectively. The most sensitive and distinctive lines in the region covered, for the kind of excitation employed, are collected in Table 5, which also includes lines of other heavy elements for comparison.

In the spectra of protactinium and neptunium, the existence of wide hyperfine structure was apparent even at the moderate dispersions employed (5.5 A/mm in the first order, 2.7 A/mm in the second order). One line of neptunium in particular, 3829.2, appeared to be very wide on a second order plate, and an exposure was made in the third order of the spectrograph with a 12.5-microgram sample, which resolved the first three lines of a flag pattern, with probably six components. This structure has since been confirmed[5] by interferometric measurements with hollow cathode excitation, by means of which approximately fifty other neptunium lines were found which also had six components, indicating that the nuclear spin of Np^{237} is 5/2. Hyperfine structure in protactinium has been known for some time.[6] In Tables 1 and 2, the lines exhibiting unresolved hyperfine structure are designated by the symbols "W" or "VW".

Comparison of the tables shows that all the elements through plutonium have spectra that are quite complex, containing many lines of low and comparatively uniform intensity, with little to distinguish each element

except details of wavelength. By contrast, the spectrum of americium is comparatively simple, containing few lines of much greater intensity than the other elements. To make this comparison more significant, a representative region of the spectrum was examined in detail for all of the elements and compared with rare earth elements. The region is defined by two strong copper lines at 4062.6 and 4275.1, respectively, and is shown in Figure 1. The figure contains exposures of 10-microgram amounts of the individual rare earths and 100-microgram amounts of the heavy elements, with a copper blank in between, exposed in the second order of the spectrograph. The ten-fold increase in sample size for the heavy elements corresponds to the intensity ratio of the strongest lines of the average rare earth and heavy element, but it is clear from the complexity of the heavy element exposures shown in the figure that the latter contain many more weak lines. The much greater intensity of the strong europium and americium lines is difficult to reproduce in a figure of this sort. In order to make this comparison more evident, the lines in this region have been tabulated by intensity groups for each element and are presented in Table 6. (Some weak lines of intensity 10 included in Table 6 were omitted from Tables 1, 2, and 3.) By dividing the total intensity listed for each element by the number of lines, an average line intensity for each element can be obtained. These average intensities are plotted in Figure 2. The comparatively uniform averages shown for the first five members of each group and the much greater average intensity of europium and americium suggest that there is a close analogy between the two groups of elements.

The relatively simple spectrum of europium is due to the fact that it contains seven f electrons, which form half of a closed shell of f electrons. It is a characteristic of half-closed shells that, while they produce a great many terms in the energy level diagram, there is one term of maximum possible multiplicity and zero orbital angular momentum which is considerably lower in energy than all the other terms of the configuration, the separation being of the order of 15,000 or 20,000 cm^{-1}. In the case of the configuration f^7, the lowest term is $^8S_{7/2}$. Because of the considerable energy difference between the lowest term and the other terms, the latter are practically never populated. Hence we may say that the situation in the ground state of the neutral europium atom, in which two s electrons are added to the f^7 core of Eu III, is analogous to the situation in neutral barium, in which two s electrons are added to the xenon-like core of Ba III. The only difference for practical purposes is that in the former case, the parent term of the core is an octet instead of $^1S_0$, the increased multiplicity leading to a comparatively small increase in the number of terms of neutral and singly ionized europium, compared with barium. On the other hand, a configuration consisting of other than seven f electrons, as in samarium, produces terms that, while slightly less numerous, are much more closely spaced and well populated. Hence the spectra of these elements are roughly equivalent to that of europium repeated a very large number of times. The effective number of such levels is not greatly different for different numbers of f electrons in the core, which explains the relatively constant line intensities of different rare earths. In the present case, the important distinction between the different rare earths is the fact that the Eu III core consists of only one term for practical purposes. These facts are illustrated in Figure 3, which compares the gross features of the energy level diagrams of barium and europium.

On the basis of these considerations, the simple spectrum of americium is strong evidence for the existence of the presence of seven f electrons. It may be noted that this finding is not in agreement with the prediction of W. F. Meggers,[7] who assigned to the neutral americium atom the configuration $5f^6 6d7s^2$. This prediction apparently was due in part to the fact that the neutral uranium atom has the configuration $5f^3 6d7s^2$, instead of having four 5f electrons and no d electron, which one might expect by analogy with neodymium. Since we believe that the normal state of Am I is $5f^7 7s^2$, by analogy with europium, it is uncertain just where the correspondence between the two groups of rare earths breaks down between uranium and americium. It also seems probable from the rare earth analogy that the spectrum of curium will be complex and resemble that of gadolinium.

The fact that the americium spectrum is comparatively simple has led to the hope that it might be possible, with comparatively little effort, to achieve a successful term analysis by inspection, using as a guide the Eu I and Eu II spectra, which have already been analyzed. Examination of the europium spectrum as excited in the copper spark source used in this study shows that practically all the lines observed belong to Eu II, which is, from the considerations enumerated above, almost alkali like. From the fairly close correspondence of the energies of the 6p and 5d electrons in Eu II with those in Ba II, it was expected that the locations of these configurations in Am II could be judged from the corresponding configurations in Ra II, which would displace corresponding multiplets slightly toward the violet and increase the multiplet separations two- to the three-fold, compared to europium. Unfortunately, the similarity is not readily apparent. It is not believed that this circumstance casts doubt on the interpretation of the electron configurations of americium, but that it is probably due to the larger multiplet separations, which produce more overlapping. It is believed that a beginning on the term analysis of Am II can nevertheless be made without great difficulty, and to this end the description of the americium spectrum is being improved.

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Table 1. Sensitive Lines of Protactinium.

Wavelength, A	Intensity	Remarks	Wavelength	Intensity	Remarks
2640.3	100		2980.5	100	
2644.9	20		2981.9	20	VW
2651.6	20		2982.9	20	
2670.5	50		2983.4	20	
2672.1	50		2984.7	50	
2697.5	50		2985.3	10	
2732.2	100		2986.4	10	VW
2743.2	100		2987.0	20	
2743.9	200		2987.9	100	
2755.9	20		2991.6	20	VW
2793.3	50		2992.7	50	
2796.2	100		2994.9	50	
2808.0	20		2997.7	50	
2811.5	50		3004.6	100	
2815.4	20		3005.7	50	
2826.6	50		3009.5	50	
2832.6	50		3015.2	50	
2835.5	50		3023.5	50	
2843.3	50		3025.3	100	
2845.5	50		3033.6	50	
2855.4	20		3034.3	50	
2870.0	50		3036.7	20	
2871.4	50		3039.0	20	
2873.3	50		3042.0	100	
2891.0	20		3042.7	50	
2893.0	100		3045.6	50	
2906.3	20		3051.8	20	VW
2906.9	50		3053.5	100	
2907.5	50		3054.6	100	
2909.0	50		3057.9	20	
2909.6	100		3058.1	10	
2922.8	50		3059.1	20	
2923.4	10		3060.0	10	
2928.3	50		3060.3	20	
2932.9	20		3060.9	20	
2934.3	50		3066.4	50	
2940.2	100		3067.7	20	
2943.0	50		3068.4	10	
2943.5	100		3069.1	10	
2954.6	50		3070.3	20	
2959.7	100		3071.2	10	
2968.0	50		3075.6	20	
2969.0	50		3076.7	20	
2970.7	20		3081.3	10	
2972.4	20		3082.3	20	
2974.0	50		3083.2	50	
2977.2	20		3092.6	20	

Table 1a-Continued

Wavelength, A	Intensity	Remarks
3093.2	50	
3103.8	20	
3105.9	50	
3111.7	50	
3117.7	20	
3131.2	20	
3136.9	20	
3157.6	20	
3170.8	20	
3171.5	20	
3175.9	10	
3178.2	20	VW
3179.6	20	VW
3203.1	10	
3204.2	20	
3205.4	20	
3205.9	10	
3214.0	50	
3221.9	20	
3240.5	20	
3332.8	20	
3394.4	10	
3448.4	10	
3452.8	10	
3468.2	10	
3471.1	10	
3480.8	10	
3488.9	10	
3545.0	50	
3632.4	50	
3643.8	20	
3663.2	20	
3665.6	10	
3666.3	10	
3668.4	10	
3674.9	20	
3679.8	20	
3692.8	20	
3705.9	10	
3713.4	10	
3716.8	20	
3717.3	10	
3725.0	10	
3725.6	10	
3729.3	20	
3730.4	10	
3731.0	10	
[illegible]	20	
3735.7	20	
3737.8	20	
3743.5	10	
3754.3	20	VW
3763.5	10	
3764.1	10	
3765.7	20	
3780.9	20	
3781.3	10	
3793.7	10	
3795.6	20	
3797.7	10	
3798.0	10	
3802.8	20	
3803.3	10	VW
3807.4	20	
3814.0	20	
3818.2	20	
3823.6	20	
3828.4	20	
3835.4	10	
3849.9	50	VW
3856.9	50	VW
3865.4	10	
3866.8	10	
3868.5	20	
3875.9	50	
3878.5	10	VW
3890.6	10	
3891.5	10	
3892.6	20	
3905.0	20	
3908.0	50	VW
3909.1	20	
3909.6	20	
3911.3	20	
3915.1	10	
3916.2	10	
3921.5	20	
3923.9	10	
3926.0	10	
3926.9	10	
3928.7	50	
3944.0	20	
3945.9	20	VW
3952.6	20	
3953.4	10	
3956.6	20	

Table 1--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
3957.8	100	VW	4107.9	20	
3959.1	10		4108.4	20	
3961.5	50		4110.8	10	
3961.8	10		4117.1	10	
3962.3	10		4128.7	20	
3962.9	10		4129.3	20	
3964.2	10		4139.6	20	
3965.7	10		4153.4	10	
3967.3	20		4159.2	10	
3970.0	50		4160.1	50	
3975.4	20		4161.0	20	
3979.5	10		4161.5	20	
3980.1	10		4164.2	50	
3980.3	10		4176.1	20	VW
3982.2	20		4189.0	10	
3983.3	20		4192.1	50	
3988.3	20		4196.9	50	
3997.7	10		4197.8	50	
3999.4	10		4205.3	20	
4000.2	10		4210.4	20	
4000.9	10		4210.9	10	
4009.4	10		4217.2	100	
4012.4	10		4225.0	10	
4012.9	50	VW	4230.6	50	
4018.2	50	VW	4231.0	10	
4029.9	20	VW	4248.1	100	
4046.9	20		4286.7	50	
4047.6	20		4291.3	50	
4051.8	20		4298.4	10	
4056.1	50	VW	4299.4	20	
4070.4	50	VW	4304.0	10	VW
4074.3	20		4311.3	10	
4087.8	20	VW	4329.2	10	
4089.4	20	VW	4338.8	10	
4090.4	20		4361.9	10	
4099.2	20		4369.3	10	
4102.1	50	VW	4371.7	20	

Table 2. Sensitive Lines of Neptunium.

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
2655.0	20		3730.7	10	
2669.6	20		3751.0	10	
2678.2	20		3780.6	10	
2733.7	20		3792.9	10	
2734.5	20		3794.9	20	
2785.2	20		3829.2	50	VW
2789.8	20		3832.3	20	W
2833.6	20		3853.2	10	W
2841.0	20		3865.2	20	
2841.5	20		3870.9	10	W
2864.1	20		3883.1	10	W
2864.4	20		3888.2	20	W
2865.5	20		3929.3	10	W
2866.0	20		3932.2	10	
2866.9	10		3949.2	20	
2867.6	20		3949.7	10	
2869.8	20	VW	3951.0	10	
2873.3	20		3954.4	10	
2888.5	10		3961.6	10	
2956.6	50		3967.4	10	W
2957.9	50		3987.0	20	
2968.2	20		3988.6	20	
2971.1	20		3989.8	20	
2974.3	50		4000.4	10	W
2974.9	50		4004.2	10	
3026.4	50		4015.5	10	
3027.3	20		4028.9	20	W
3029.1	20		4031.6	10	
3052.0	50	W	4031.8	10	
3057.5	20		4050.1	10	VW
3070.3	20	W	4051.1	10	W
3078.0	50		4077.4	10	
3084.7	20		4086.8	10	
3090.4	20		4098.8	10	W
3092.0	20		4108.4	20	W
3092.5	20		4121.2	10	
3164.8	10		4123.3	10	
3171.6	20		4136.9	10	
3185.9	10		4156.3	10	VW
3315.7	10		4164.5	50	
3337.0	10		4165.3	10	
3402.5	20		4172.0	10	VW
3589.2	10		4182.1	10	W
3590.6	20		4192.7	10	
3665.6	20	W	4196.6	10	
3708.3	20	W	4197.1	10	
3711.8	10	W	4208.5	10	
3716.2	10	W	4209.7	10	
3722.3	20	W	4234.8	10	

Table 2--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
4246.8	10		4290.9	50	
4256.7	20		4296.1	10	W
4258.1	20	W	4307.8	20	
4269.6	10	W	4319.8	10	W
4273.2	10		4333.9	10	
4279.6	20	W	4336.6	20	
4281.4	10	W	4351.9	10	W
4289.7	10		4363.8	10	

Table 3. Sensitive Lines of Plutonium.

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
2677.0	20		2967.3	20	
2682.9	10		2968.9	50	
2683.4	10		2970.2	50	
2684.8	20		2972.3	100	
2693.3	20		2977.1	20	
2781.3	50		2977.8	50	
2784.4	50		2978.4	20	
2787.2	20		2980.0	50	
2803.9	10		2981.2	20	
2806.0	20		2986.9	20	
2808.4	50		2988.1	100	
2809.0	20		2991.5	20	
2815.6	50		2993.9	100	
2826.2	20		2996.4	100	
2833.2	50		3000.4	100	
2835.5	100		3008.9	50	
2898.0	50	diffuse	3009.6	50	
2899.8	20		3028.8	20	
2904.3	20		3042.5	20	
2905.0	50		3043.0	20	
2910.3	50		3060.2	10	
2912.7	20		3069.3	20	
2913.7	20		3089.6	10	
2914.2	20		3090.5	10	
2914.9	20		3091.2	20	
2915.6	50		3091.9	20	
2918.0	20		3092.7	50	
2925.2	100		3093.3	20	
2925.8	50		3104.1	20	
2926.3	20		3105.0	20	
2928.2	50		3105.9	20	
2929.5	10		3117.8	10	
2930.9	20		3118.5	10	
2932.4	20		3123.8	20	
2933.2	20		3136.5	20	
2933.8	20		3159.2	50	
2937.6	50		3161.5	10	
2938.4	10		3163.1	10	
2938.9	100		3174.4	10	
2941.3	50		3179.3	20	
2945.2	50		3198.3	10	
2945.9	50		3220.8	10	
2950.0	20		3221.4	20	
2951.6	50	VW	3231.8	20	
2954.3	100		3232.6	20	
2964.5	20		3312.6	20	
2966.7	20		3401.0	20	

Table 3--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
3465.0	10		3895.9	20	
3469.2	10		3904.1	50	
3473.6	10		3907.2	100	
3585.9	20		3910.3	20	
3627.5	10		3912.5	50	
3632.1	20		3913.4	50	
3709.1	20		3928.0	20	
3714.7	10		3928.5	20	
3718.1	20		3931.2	20	
3720.2	20		3944.0	10	
3720.6	20		3947.0	10	
3721.5	20		3949.2	20	
3726.0	50		3953.0	20	
3726.8	50		3958.9	20	
3732.1	20		3961.5	50	
3739.4	10		3962.8	20	
3743.1	10		3963.6	20	
3753.6	20		3964.9	10	
3755.9	20		3967.3	20	
3758.3	20		3972.2	50	
3772.8	10		3975.4	50	
3773.6	20		3976.0	20	
3774.4	10		3979.8	10	
3775.7	20		3980.4	20	
3776.8	10		3984.0	10	
3792.2	20		3985.5	100	
3803.6	20		3988.5	20	
3810.2	20		3989.7	100	
3812.3	20		3990.2	10	
3814.9	20		3991.5	20	
3823.9	20		3992.2	20	
3827.5	20		4010.6	10	
3835.5	20		4013.1	10	
3836.9	20		4015.9	20	
3842.1	10		4021.5	50	
3851.9	10		4048.9	10	
3852.7	50		4064.6	20	
3864.4	10		4066.8	20	
3864.7	10		4078.0	20	diffuse
3865.0	10		4101.0	20	
3869.7	10		4102.0	20	
3870.1	10		4104.4	10	
3874.2	20		4105.9	10	
3878.6	20		4107.2	10	
3886.4	10		4116.4	20	
3886.5	10		4140.0	10	
3887.4	20		4141.2	20	
3892.7	20		4190.0	10	diffuse

Table 3--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
4196.2	50		4273.3	100	
4204.7	10		4278.4	10	
4205.5	10		4278.8	10	
4206.4	10		4280.3	20	
4208.0	10		4283.7	10	
4208.2	10		4289.1	20	diffuse
4208.8	10		4297.8	10	
4219.0	10		4298.2	10	
4229.7	20		4314.3	10	
4247.2	10		4316.7	10	
4254.4	20	Cr 4254.35?	4330.6	20	
4254.8	20		4336.1	10	
4256.0	20		4337.2	20	
4257.9	20		4352.7	50	
4261.8	10		4358.1	20	

Table 4. Sensitive Lines of Americium.

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
2661.6	20		2982.2	100	
2664.8	20		2993.5	50	
2668.8	20		2994.4	20	
2686.9	20		3004.3	200	
2691.4	100		3020.7	100	
2706.4	50		3021.1	50	
2716.5	50		3028.0	200	
2720.5	20		3028.8	20	
2725.4	20		3037.4	20	
2727.6	20		3037.8	100	
2728.7	200		3047.6	20	
2731.9	20		3057.4	20	
2732.1	20		3059.1	50	
2735.4	100		3071.3	100	
2739.6	100		3082.8	100	
2742.3	50		3162.1	500	
2743.2	100		3162.9	100	
2746.6	100		3203.3	100	
2747.0	100		3314.0	100	
2749.4	500		3332.1	100	
2749.8	20		3362.5	50	
2753.4	20		3392.0	50	
2755.3	200		3428.0	20	
2755.9	200		3431.6	20	
2756.7	500		3439.8	200	
2776.0	50		3446.0	50	
2776.5	50		3448.2	50	
2796.8	50		3452.0	100	
2812.9	200		3509.5	50	
2815.3	100		3510.2	100	
2816.0	50		3547.9	100	
2816.4	50		3559.6	50	
2832.3	2000		3561.8	50	
2852.2	100		3562.6	200	
2861.6	50		3569.2	100	
2873.3	100		3570.0	100	
2881.6	50		3573.1	100	
2888.5	200		3573.6	100	
2893.3	100		3581.2	200	
2899.6	100		3584.7	100	
2911.2	500		3593.7	100	
2920.6	500		3615.8	20	
2928.0	100		3616.5	20	
2937.0	100		3617.4	20	
2957.0	200		3631.4	50	
2966.8	500		3639.5	20	
2969.4	500		3673.1	200	
2972.6	200		3683.4	50	

Table 4--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
3696.4	200		3963.3	50	
3706.2	100		3973.1	100	
3707.9	100		3975.2	50	
3710.3	100		3982.6	20	
3712.9	50		3984.6	50	
3720.0	50		3991.9	50	
3720.5	50		4000.6	50	
3721.2	20		4003.0	20	
3725.4	50		4006.2	20	
3733.0	20		4009.2	100	
3734.7	20		4013.7	100	
3737.1	20		4017.9	20	
3737.6	50		4019.7	100	
3740.4	50		4020.2	50	
3748.3	20		4021.3	20	
3749.4	50		4027.4	50	
3751.0	50		4027.8	50	
3752.6	100		4032.9	20	
3753.2	100		4033.5	20	
3757.7	200		4036.4	200	
3761.6	500		4057.8	50	
3767.1	20		4069.8	50	
3769.0	20		4079.7	20	
3774.3	20		4080.5	20	
3777.4	500		4089.3	1000	
3788.7	50		4099.0	20	
3789.0	20		4102.3	20	
3801.7	100		4107.0	20	
3848.9	100		4108.8	20	
3871.5	500		4109.5	20	
3892.9	20		4109.9	20	
3896.0	20		4124.5	20	
3901.5	50		4127.4	20	
3904.2	100		4128.3	20	
3914.3	100		4128.9	20	
3916.0	500		4130.7	20	
3921.5	500		4136.7	20	
3926.2	1000		4137.7	20	
3936.2	100		4144.0	20	
3942.7	20		4148.0	20	
3943.8	50		4149.9	20	
3944.0	100		4154.7	50	
3944.5	50		4182.6	20	
3945.2	20		4184.0	20	
3946.0	50		4184.3	20	
3948.0	20		4186.6	50	
3950.3	20		4188.2	500	
3952.5	500		4188.8	20	

Table 4--Continued

Wavelength, A	Intensity	Remarks	Wavelength, A	Intensity	Remarks
4189.6	20		4289.3	100	
4197.6	20		4289.9	20	
4198.7	20		4300.9	20	
4200.0	50		4302.5	20	
4219.4	20		4302.8	20	
4221.0	20		4309.7	100	
4226.8	100		4309.9	50	
4233.6	20		4324.6	500	
4234.0	20		4332.8	100	
4248.4	500		4335.6	50	
4249.4	20		4337.2	20	
4249.9	50		4341.8	20	
4252.0	20		4348.3	50	
4261.8	50		4349.3	50	
4262.4	20		4366.7	100	
4265.6	200		4372.4	50	
4272.2	20		4374.9	50	
4278.2	20				

Table 5. Sensitive Lines of the Heavy Elements.

Element	Wavelength, A	Intensity
Th	4019.1	1000
Pa	3957.8	100
	3054.6	100
	3053.5	100
U	3932.0	100
Np	4290.9	50
	3829.2	50
Pu	3989.7	100
	3907.1	100
Am	2969.4	500
	2832.3	2000

Table 6. Statistical Comparison of Rare Earth and Heavy Element Spectra, 4062-4275 A.

Element	No. Lines in Each Intensity Group 10	20	50	100	200	500	1000	2000	5000	10000	20000	Total Intensity	No. Lines	Intensity per Line
Ba	0	1	0	0	0	1						520	2	260
La	0	0	1	0	4	3	1	3	1	1		24350	14	1739
Ce	20	29	19	32	6	3						7630	109	70
Pr	8	11	18	9	6	4	1					6300	57	111
Nd	5	13	18	8	8	3						5500	55	100
61														
Sm	5	9	17	18	11	5	1					8850	66	134
Eu	0	0	3	1	1	0	1	0	0	1	1	31450	8	3931
Gd	3	6	12	9	9	1	1					4950	41	121
Ra	0	0	1	0	0	0	0	1				2050	2	1025
Ac														
Th	26	27	10	4	3							2300	70	33
Pa	24	15	8	2								1140	49	23
U	43	20	7	0	1							1380	71	19
Np	20	3	1									310	24	13
Pu	28	12	1	1								670	42	16
Am	0	33	6	1	1	2	1					3260	44	74

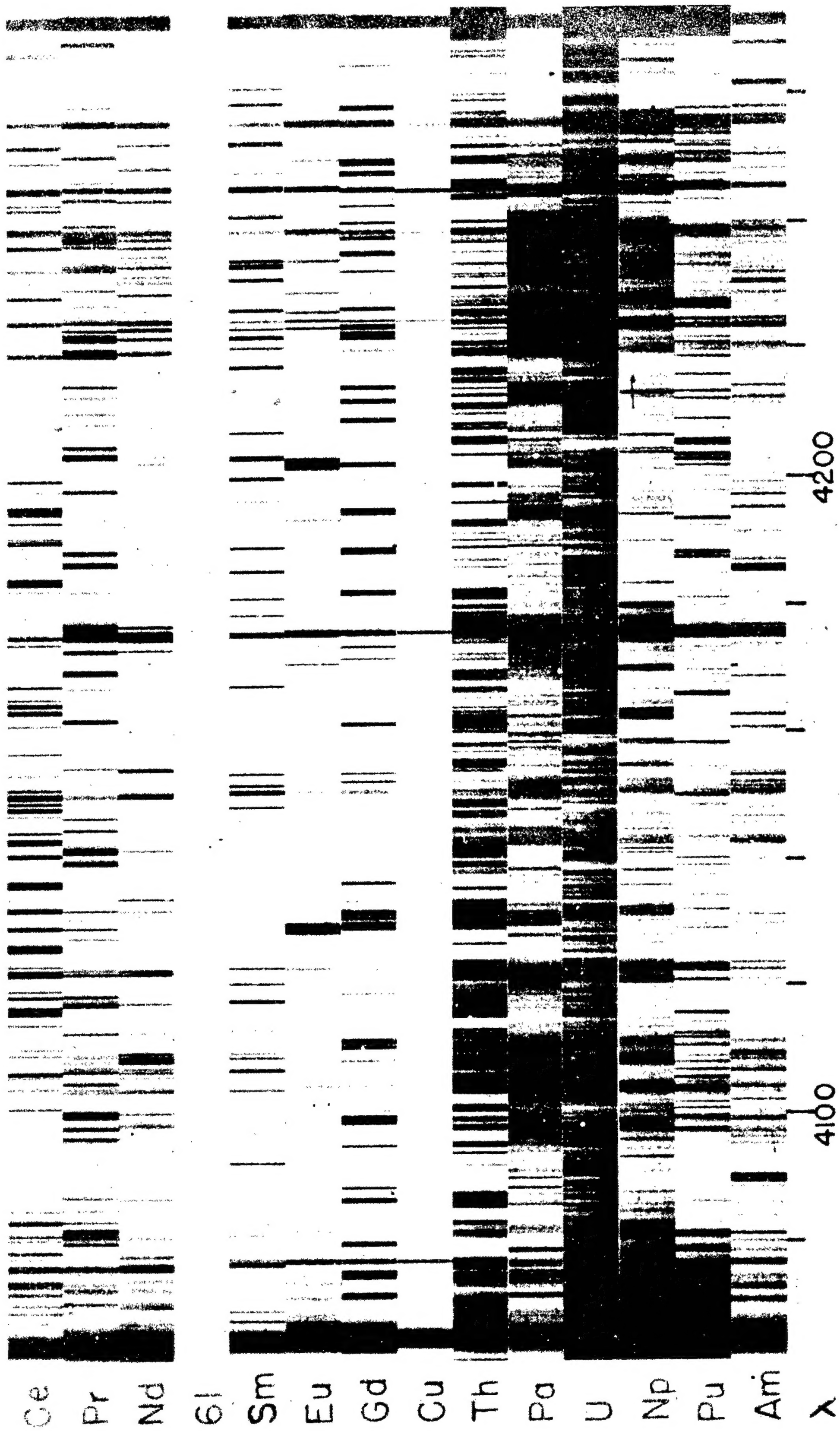
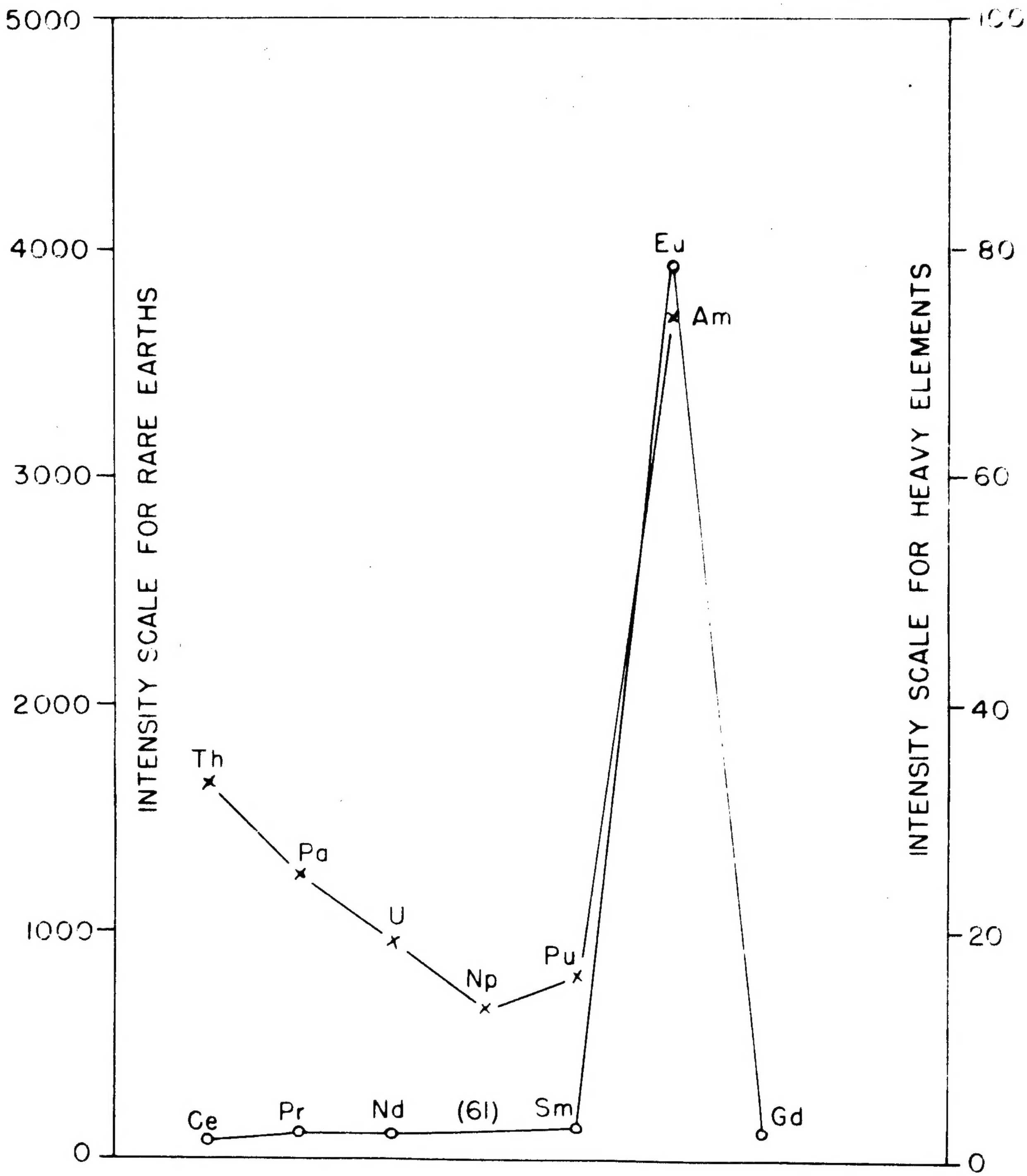


Figure 1.



AVERAGE LINE INTENSITY FOR RARE EARTHS AND HEAVY ELEMENTS IN THE REGION 4062 - 4275 A

FIGURE 2

LOW TERMS OF BARIUM AND EUROPIUM

FIGURE 3

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